Experimental Investigation of Friction Coefficient and Wear Rate of Stainless Steel 202 Sliding against Smooth and Rough Stainless Steel 304 Couter-faces

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Abstract

In the present study, friction coefficient and wear rate of stainless steel 202 (SS 202) sliding against mild steel are investigated experimentally using a pin on disc apparatus designed and fabricated. Experiments are carried out when smooth or rough SS 304 pin slides on SS 202 disc. Experiments are conducted at normal load 10, 15 and 20 N, sliding velocity 1, 1.5 and 2 m/s and relative humidity 70%. Variations of friction coefficient with the duration of rubbing at different normal loads and sliding velocities are investigated. Results show that friction coefficient is influenced by duration of rubbing, normal load and sliding velocity. In general, friction coefficient increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. The obtained results reveal that friction coefficient decreases with the increase in normal load for SS 202 mating with smooth or rough SS 304 counter-face. On the other hand, it is also found that friction coefficient increases with the increase in sliding velocity. Moreover, wear rate increases with the increase in normal load and sliding velocity. The magnitudes of friction coefficient and wear rate are different depending on sliding velocity and normal load for both smooth and rough counter-face pin materials.

Keywords

Friction Coefficient; Wear Rate; SS 202; SS 304; Normal Load; Sliding Velocity

Introduction

Numerous investigations have shown that friction coefficient depends on a number of parameters such as normal load, geometry, relative surface motion, sliding velocity, surface roughness of the rubbing surfaces, type of material, system rigidity, temperature, stick-slip, relative humidity, lubrication and vibration. Among these factors normal load and sliding velocity are the two major factors that play significant role in the variation of friction. In the case of materials with surface films which are either deliberately applied or produced by reaction with environment, the coefficient of friction may not remain constant as a function of load. In many metal pairs in the high load regime, the coefficient of friction decreases with load. Bhushan (1996) and Blau (1992) reported that increased surface roughness and a large quantity of wear debris are believed to be responsible for decrease in friction. It was observed that the coefficient of friction may be very low for very smooth surfaces and/or at loads down to micro-to nanonewton range [Bhushan (1999), Bhushan & Kulkarni (1996)].

The third law of friction which states that friction is independent of velocity, is not generally valid. Friction may increase or decrease as a result of increased sliding velocity for different material combinations. An increase in the temperature generally results in metal softened in

the case of low melting point metals. An increase in temperature may result in solid-state phase transformation which may either improve or degrade mechanical properties [Bhushan (1999)]. The most drastic effect occurs if a metal approaches its melting point and its strength drops rapidly, and thermal diffusion and creep phenomena become more important. The resulting increased adhesion at contacts and ductility lead to an increase in friction [Bhushan (1999)]. The friction coefficient increases with increased sliding velocity due to more adhesion of counterface material (pin) on disc.

Nowadays, stainless steel-stainless steel combinations are widely used for sliding/rolling applications where low friction is required. Due to these wide ranges of tribological applications, SS 202-SS 304 combination for smooth and rough counterface has been selected in this research study. It is expected that the applications of these results will contribute to the different concerned mechanical processes.

In this research, it is aimed to find the relation between friction/wear and steel sliding pair with different counter-face surface roughnesses, as well to reveal the influence of normal load and sliding velocity on friction and wear of SS 202. Within this research, it is sought to better understand and investigate scientifically the possibility of applying controlled normal load and sliding velocity with appropriate choice of counterface surface condition, which may significantly improve the performance of machine elements in industry.

It was reported [Chowdhury & Helali (2008), Chowdhury et al. (2009, 2011)] that friction coefficient of metals and alloys showed different behavior under different operating conditions. In spite of these investigations, the effects of normal load and sliding velocity on friction coefficient of SS 202 sliding against SS 304 for smooth or rough counter-face are not yet to be clearly understood. Therefore, in this study, an attempt has been made to investigate the effect of normal load and sliding velocity on the friction coefficient of SS 202 sliding against smooth or rough SS 304 counter-face. The effect of duration of rubbing on friction coefficient of SS 202 has also been examined in this study. In addition, the effect of normal load and sliding velocity on wear rate of SS 202 was investigated.

Experimental

A schematic diagram of the experimental set-up is shown in Fig. 1 i.e. a pin which can slide on a rotating horizontal surface (disc). In this set-up, a circular test sample is to be fixed on a rotating plate (table) having a long vertical shaft clamped with screw from the bottom surface of the rotating plate. The shaft passes through two close-fit bush-bearings which are rigidly fixed with stainless steel plate and stainless steel base such that the shaft can move only axially and any radial movement of the rotating shaft is restrained by the bush. These stainless steel plate and stainless steel base are rigidly fixed with four vertical round bars to provide the rigidity to the main structure of this set-up.

The main base of the set-up is constructed by 10 mm thickness mild steel plate consisting of 3 mm thickness rubber sheet at the upper side and 20 mm thickness rubber block at the lower side. A compound V-pulley above the top stainless steel plate was fixed with the shaft to transmit rotation to the shaft from a motor. An electronic speed control unit is used to vary the speed of the motor as required. A 6 mm diameter cylindrical pin whose contacting foot is flat, made of mild steel, fitted on a holder is subsequently fitted with an arm. The arm is pivoted with a separate base in such a way that the arm with the pin holder can rotate vertically and horizontally about the pivot point with very low friction. Sliding speed can be varied by two ways (i) by changing the frictional radius and (ii) by changing the rotational speed of the shaft.

In this research, sliding speed is varied by changing the rotational speed of the shaft while maintaining 25 mm constant frictional radius. To measure the frictional force acting on the pin during sliding on the rotating plate, a load cell (TML, Tokyo Sokki Kenkyujo Co. Ltd, CLS-10NA) along with its digital indicator (TML, Tokyo Sokki Kenkyujo Co. Ltd, Model no. TD-93A) was used. The coefficient of friction was obtained by dividing the frictional force by the applied normal force (load). Wear was measured by weighing the test sample with an electronic balance before and after the test, and then the difference in mass was converted to wear rate.

To measure the surface roughness of the test samples, Taylor Hobson Precision Roughness Checker (Surtronic

25) was used. Each test was conducted for 30 minutes of rubbing time with a new pin and test sample. Furthermore, to ensure the reliability of the test results, each test was repeated five times and the scatter in results was small, therefore the average values of these test results were taken into consideration. The detail experimental conditions are shown in Table 1. The chemical composition and hardness of pin (SS 304) and disc (SS 202) materials are presented in Table 2 and Table 3.

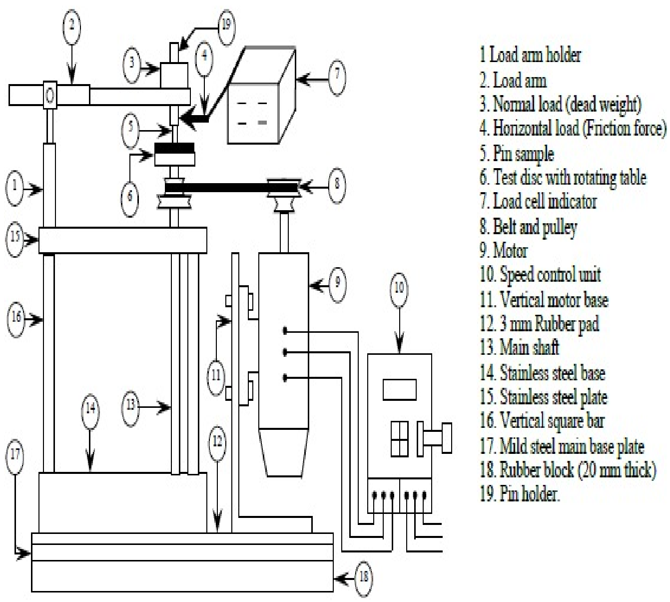

FIG. 1 BLOCK DIAGRAM OF THE EXPERIMENTAL SET-UP

TABLE 1: EXPERIMENTAL CONDITIONS

Sl. No.	Parameters	Operating Conditions
1	Normal Load	10, 15, 20 N
2	Sliding Velocity	1, 1.5, 2 m/s
3	Relative Humidity	70 (± 5)%
4	Duration of Rubbing	30 minutes
5	Surface Condition	Dry
6	Disc material	Stainless steel 202 (SS 202)
7	Roughness of SS 202, R_a	0.35-0.45 mm
8	Pin material	Stainless steel 304 (SS 304)
9	Roughness of SS 304, R_a	(a) Smooth counterface: about 0.35 mm
		(b) Rough counterface: about 3.5 mm

TABLE 2: CHEMICAL COMPOSITION OF TESTED MATERIALS

Chemical Element	Content (%)	
	SS-202	SS-304
Carbon	0.12	0.08
Manganese	5.5-7.5	2
Silicone	0.9	1
Chromium	16-18	18-20
Nikel	0.5-4.0	8.0-12.0
Molybdenum	0.2	0.02
Phosphorus	0.06	0.045
Nitrogen	0.25	-
Sulphur	-	0.03

TABLE 3: HARDNESS OF THE TESTED MATERIALS

Hardness Method	Hardness	
	SS-202	SS-304
Rockwell	85-95	70-80
Brinell	180-190	145-155

Results and Discussion

Variation of Friction Coefficient with Duration of Rubbing at Different Normal Loads

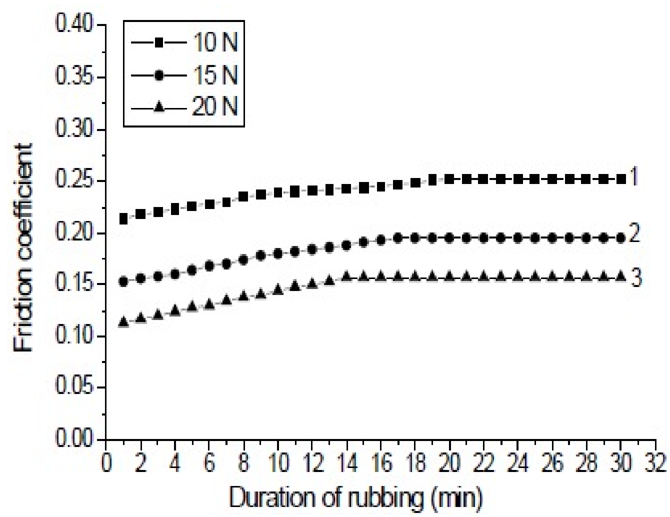

FIG. 2 FRICTION COEFFICIENT AS A FUNCTION OF DURATION OF RUBBING AT DIFFERENT NORMAL LOADS (SLIDING VELOCITY: 1 M/S, RELATIVE HUMIDITY: 70%, TEST SAMPLE: SS 202, PIN: SS 304, SMOOTH)

Figure 2 shows the variation of friction coefficient with the duration of rubbing at different normal loads for SS 202 mating with smooth SS 304 counter-face. During experiment, the sliding velocity and relative humidity were 1 m/s and 70% respectively. Curve 1 of this figure is drawn for normal load 10 N. From this curve, it is observed that during initial stage of rubbing, the value

of friction coefficient is 0.214 and then increases very steadily up to 0.252 over a duration of 20 minutes of rubbing and after that it remains constant for the rest of the experimental time.

At the initial stage of rubbing, friction is low and the factors responsible for this low friction are due to the presence of a layer of foreign material on the disc surface. This layer on the disc surface in general comprises (i) moisture, (ii) oxide of metals, (iii) deposited lubricating material, etc. SS 202 readily oxidizes in air, so that, at initial duration of rubbing, the oxide film easily separates the two material surfaces and there is little or no true metallic contact and also the oxide film features low shear strength. After initial rubbing, the film (deposited layer) breaks up and clean surfaces come in contact which increase the bonding force between the contacting surfaces.

At the same time due to the ploughing effect, inclusion of trapped wear particles and roughening of the disc surface, the friction force increases with duration of rubbing. After certain duration of rubbing, the increase of roughness and other parameters may reach a certain steady state value and hence the values of friction coefficient remain constant for the rest of the time. Curves 2 and 3 of this figure are drawn for normal load 15 and 20 N respectively and show similar trends as that of curve 1. From these curves, it is also observed that time to reach steady state values is varying for different normal loads. Results show that at normal load 10, 15 and 20 N, SS 202-SS 304 smooth pair takes 20, 17 and 14 minutes respectively to reach steady friction, indicating that the higher the normal load is, the less the time to reach steady friction is. This is because the surface roughness and other parameter attain a steady level at a shorter period of time with the increase in normal load. The trends of these results are similar to the results of Chowdhury and Helali [Chowdhury & Helali (2006, 2008)].

Figure 3 shows the effect of the duration of rubbing on the value of friction coefficient at different normal loads for SS 202 sliding against rough SS 304 counter-face at sliding velocity 1 m/s and relative humidity 70%. Curve 1 of this figure drawn for normal load 10 N, shows that during starting of the experiment, the value of friction coefficient is 0.237 which rises for 22 minutes to a value of 0.28 and then it becomes steady for the rest of the experimental time. Almost similar trends of variation are observed in curves 2 and 3 which are drawn for load 15 and 20 N respectively. From these curves, it is found that time to reach steady friction is varying for different normal loads. At normal load 10, 15 and 20 N, SS 202-SS 304 rough pair takes 22, 19 and 16 minutes respectively to reach steady friction; that is, the higher the normal load is, the less time the SS 202-SS 304 rough pair takes to stabilize.

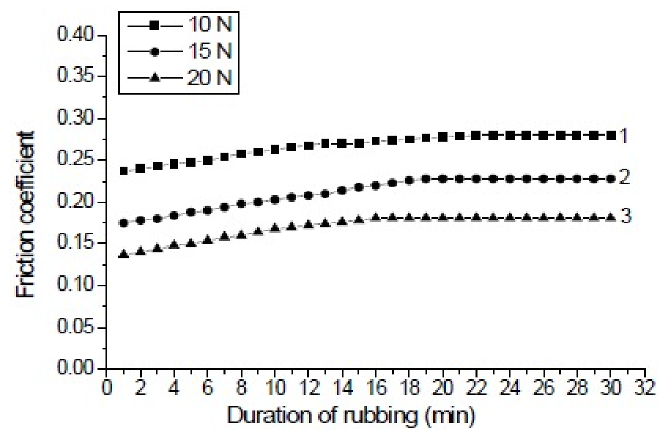

FIG. 3 FRICTION COEFFICIENT AS A FUNCTION OF DURATION OF RUBBING AT DIFFERENT NORMAL LOADS (SLIDING VELOCITY: 1 M/S, RELATIVE HUMIDITY: 70%, TEST SAMPLE: SS 202, PIN: SS 304, ROUGH)

Influence of Normal Load on Friction Coefficient

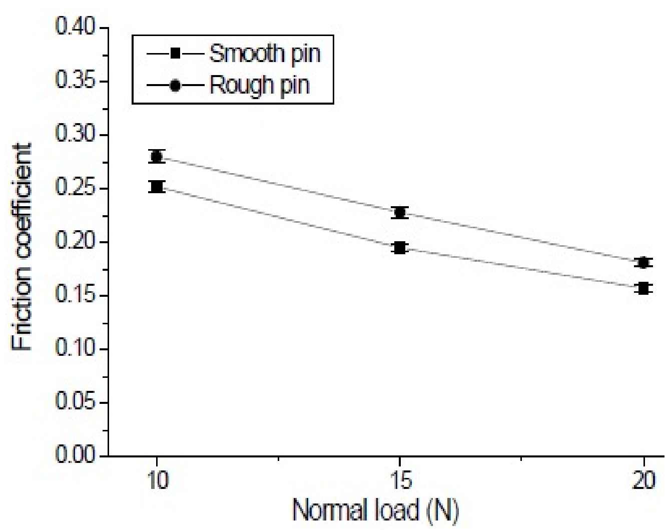

FIG. 4 FRICTION COEFFICIENT AS A FUNCTION OF NORMAL LOAD FOR SS 202 (SLIDING VELOCITY: 1 M/S, RELATIVE HUMIDITY: 70%)

Figure 4 shows the comparison of the variation of friction coefficient with normal load for SS 202 mating with smooth or rough SS 304 couter-face. It is shown that friction coefficient varies from 0.252 to 0.157 and 0.28 to 0.181 with the variation of normal load from 10 to 20 N for SS 202-SS 304 smooth and SS 202-SS 304 rough counter-face respectively. These results show that friction coefficient decreases with the increase in normal load. Increased surface roughness and a large quantity of wear debris are believed to be responsible for the decrease in friction [Bhushan (1996), Blau (1992)] with the increase in normal load. Similar behavior is obtained for Al–Stainless steel pair [Chowdhury et al. (2011)] i.e. friction coefficient decreases with the increase in normal load. From this figure, it is also found that at identical conditions, the values of friction coefficient of SS 202 mating with smooth counter-face is lower than that of SS 202 mating with rough counter-face. After friction tests, it was found that the average roughness of SS 202 varied from 0.93-1.20 and 1.19-1.39 μm for smooth and rough counterface pins respectively.

Variation of Friction Coefficient with Duration of Rubbing at Different Sliding Velocities

Figures 5 and 6 show the variation of friction coefficient with the duration of rubbing at different sliding velocities for SS 202-SS 304 smooth pair and SS 202-SS 304 rough pair respectively at normal load 15 N and relative humidity 70%. Curves 1, 2 and 3 of Fig. 5 are drawn for sliding velocity 1, 1.5 and 2 m/s respectively. Curve 1 of this figure shows that at initial stage of rubbing, the value of friction coefficient is 0.153 which increases almost linearly up to 0.195 over a duration of 17 minutes of rubbing and after that it remains constant for the rest of the experimental time. The increase of friction may be associated with ploughing effect and because of roughening of the disc surface. After certain duration of rubbing, the increase of roughness and other parameters may reach a certain steady value hence the values of friction coefficient remain constant for the rest of the time. Curves 2 and 3 show that for the higher sliding velocity, the friction coefficient is more and the trend in variation of friction coefficient is almost the same as for curve 1.

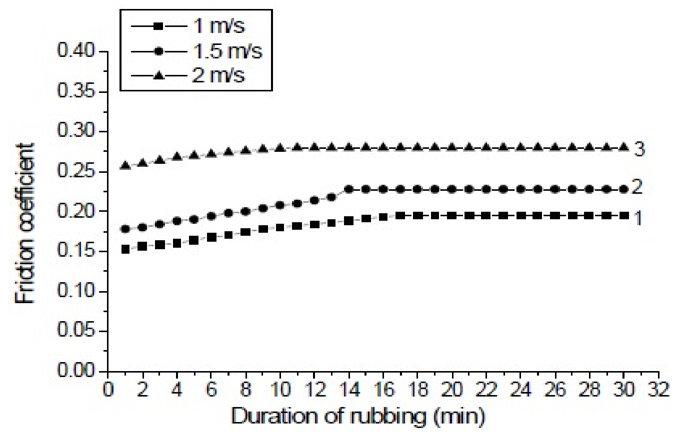

FIG. 5 FRICTION COEFFICIENT AS A FUNCTION OF DURATION OF RUBBING AT DIFFERENT SLIDING VELOCITIES (NORMAL LOAD: 15 N, RELATIVE HUMIDITY: 70%, TEST SAMPLE: SS202, PIN: SS 304, SMOOTH)

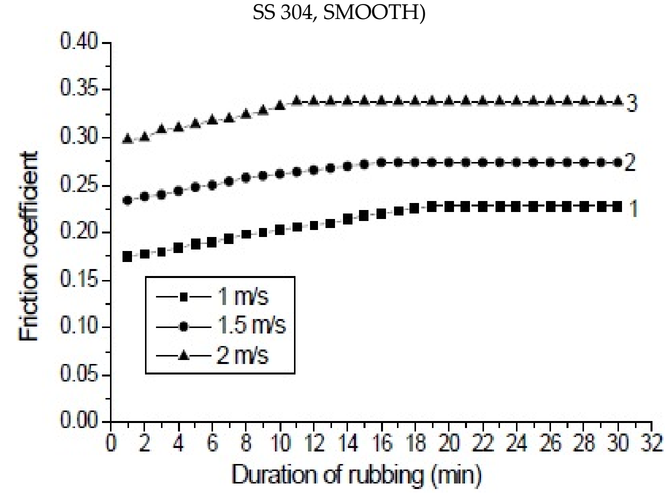

FIG. 6 FRICTION COEFFICIENT AS A FUNCTION OF DURATION OF RUBBING AT DIFFERENT SLIDING VELOCITIES (NORMAL LOAD: 15 N, RELATIVE HUMIDITY: 70%, TEST SAMPLE: SS 202, PIN: SS 304, ROUGH)

From these curves, it is also observed that the time to reach steady state value is varying for different sliding velocity. From the results it is found that SS 202-SS 304 smooth pair at sliding velocity 1, 1.5 and 2 m/s takes to reach constant friction 17, 14 and 11 minutes respectively, indicating that the higher the sliding velocity is, the less the time it takes to reach constant friction is. This may be due to that the higher the sliding velocity is, the less time the surface roughness and other parameters take to stabilize. From Fig. 6, it can be observed that the trends in variation of friction coefficient with the duration of rubbing are very similar to that of Fig. 5 but the values of friction coefficient are different for SS 202-SS 304 rough pair.

Influence of Sliding Velocity on Friction Coefficient

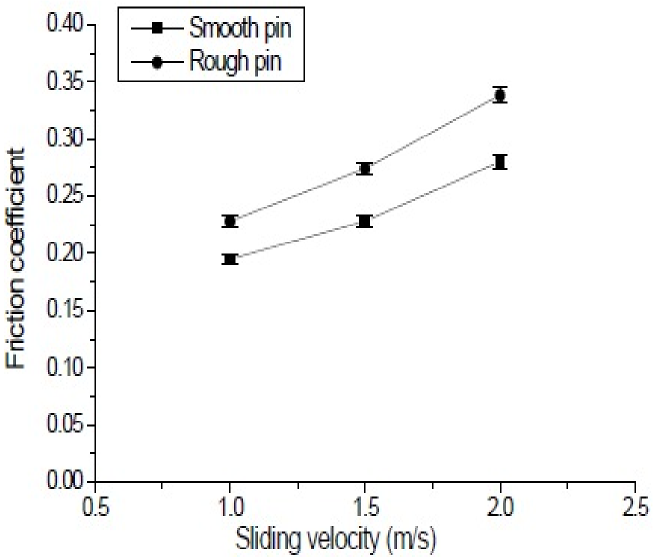

FIG. 7 FRICTION COEFFICIENT AS A FUNCTION OF SLIDING VELOCITY FOR SS 202 (NORMAL LOAD: 15 N, RELATIVE HUMIDITY: 70%)

Figure 7 shows the comparison of the variation of friction coefficient with sliding velocity for the above mentioned material pairs. Curves of this figure are drawn for SS 202-SS 304 smooth and SS 202-SS 304 rough pairs. It is shown that the friction coefficient varies from 0.195 to 0.28 and 0.228 to 0.338 with the variation of sliding velocity from 1 to 2 m/s for SS 202-SS 304 smooth and SS 202-SS 304 rough pairs respectively. These results indicate that friction coefficient increases with the increase in sliding velocity. Sliding contact of two materials results in heat generation at the asperities and hence increments in temperature at the frictional surfaces of the two materials. The increase in friction coefficient with sliding velocity is due to more adhesion of counterface material (pin) on disc [Bhushan (1999)]. From this figure, it is also found that at identical conditions, the values of friction coefficient of SS 202 sliding against smooth SS 304 counter-face are lower than that of SS 202 sliding against rough SS 304 counter-face. After friction tests, it was found that the average roughness of SS 202 varied from 1.02-1.23 and 1.23-1.45 μm for smooth and rough counter-face pins respectively.

Influence of Normal Load on Wear Rate

Variations of wear rate with normal load are presented in Fig. 8. Results show that wear rate of SS 202 varies from 3.8 to 5.6 and 4.6 to 6.18 mg/min with the variation of normal load from 10 to 20 N for smooth and rough counter-face pins respectively. It is observed that wear rate increases with the increase in normal load for both type material combinations. When the load on the pin is increased, the actual area of contact would increase towards the nominal contact area, resulting in increased frictional force between two sliding surfaces. The increased frictional force and real surface area in contact cause higher wear. This means that the shear force and frictional thrust are increased with increase of applied load and these increased in values accelerate the wear rate. Similar trends of variation are also observed for mild steel–mild steel couples [Chowdhury & Helali (2007)], i.e wear rate increases with the increase in normal load. From this figure, it is also found that at identical conditions, the values of wear rate of SS 202 mating with smooth counter-face is lower than those of SS 202 mating with rough counter-face. It is due to the fact that rough surfaces generally wear more quickly and have higher friction coefficients than smooth surfaces.

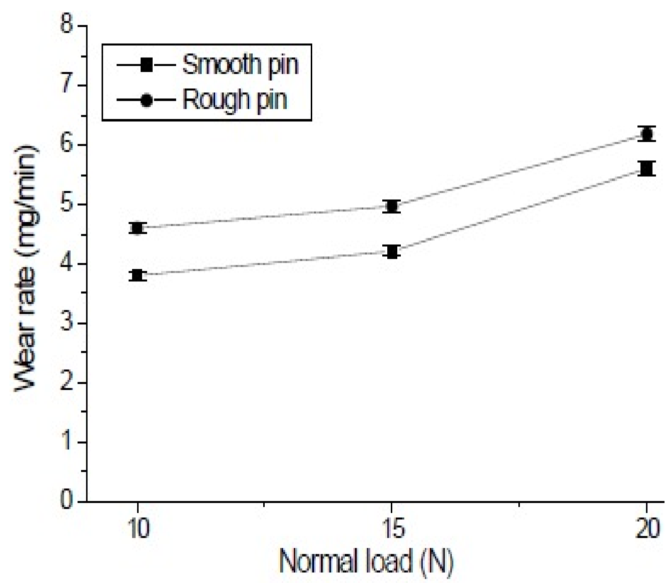

FIG. 8 WEAR RATE AS A FUNCTION OF NORMAL LOAD FOR SS 202 (SLIDING VELOCITY: 1 M/S, RELATIVE HUMIDITY: 70%)

Influence of Sliding Velocity on Wear Rate

The variations of wear rate with sliding velocity for the above mentioned material combinations are also observed in this study and the results are presented in Fig. 9. These results indicate that wear rate of SS 202 varies from 4.21 to 6.31 and 4.97 to 7.19 mg/min with the

variation of sliding velocity from 1 to 2 m/s for SS 202-SS 304 smooth and SS 202-SS 304 rough couples respectively. It is observed that wear rate increases with the increase in sliding velocity for both of these material pairs. This is due to the fact that duration of rubbing is same for all sliding velocities, while the length of rubbing is more for higher sliding velocity. The reduction of shear strength of the material and increased true area of contact between contacting surfaces may play some role in the higher wear rate at higher sliding velocity [Bhushan (1999)]. From this figure, it is also revealed that at identical conditions, wear rates of SS 202 mating with smooth counter-face are lower than those of SS 304 mating with rough counter-face.

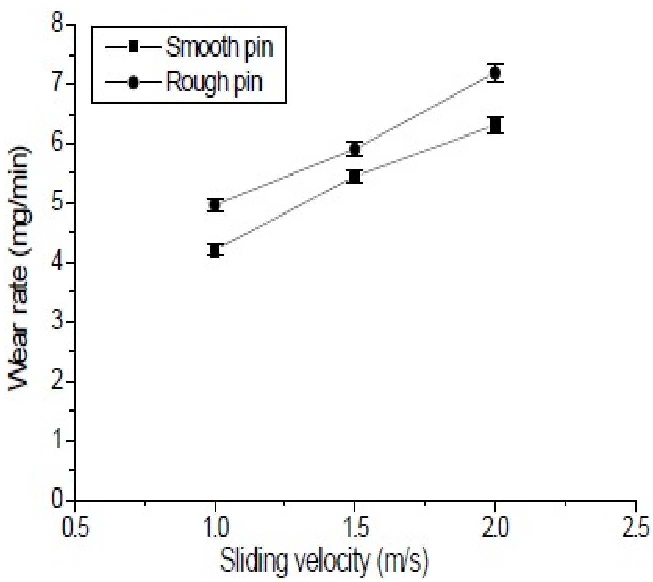

FIG. 9 WEAR AS A FUNCTION OF SLIDING VELOCITY FOR SS 202 (NORMAL LOAD: 15 N, RELATIVE HUMIDITY: 70%)

Conclusion

The presence of normal load and sliding velocity indeed affects the friction force considerably. Within the observed range, the values of friction coefficient decrease with the increase in normal load while friction coefficients increase with the increase in sliding velocity for SS 202 sliding against smooth or rough SS 304 pin. Friction coefficient varies with the duration of rubbing and after certain duration of rubbing, friction coefficient becomes steady for the observed range of normal load and sliding velocity. Wear rates of SS 202 mating with smooth or rough SS 304 counter-face increase with the increase in normal load and sliding velocity. At identical conditions, the values of friction coefficient and wear rate of SS 202 mating with smooth counter-face are lower than those of SS 202 mating with rough counter-face.

As (i) the friction coefficient decreases with the increase in normal load (ii) the values of friction coefficient increase with the rise in sliding velocity (iii) wear rate increases with the rise in normal load and sliding velocity and (iv) the magnitudes of friction coefficient and wear rate are different for smooth and rough counter-face pins, therefore maintaining an appropriate level of normal load, sliding velocity as well as appropriate choice of counter-face surface condition, friction and wear may be kept to some lower value to improve mechanical processes.

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